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A BITUMINOUS MACADAM ROAD AFTER 21 YEARS OF SERVICE

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The reports of research published in this magazine are necessarily qualified by the conditions of the tests from which the data are obtained. Whenever it is deemed possible to do so, generalizations are drawn from the results of the tests; and, unless this is done, the conclusions formulated must be considered as specifically pertinent only to the described conditions.

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RATIONALIZATION AND SIMPLIFICATION OF TEST REQUIREMENTS FOR LIQUID ASPHALTIC MATERIALS

By E. F. KELLEY, Chief Division of Tests, U. S. Bureau of Public Roads, and PREVOST HUBBARD, Chemical Engineer, The Asphalt Institute.

THE PURPOSE of test requirements in specifications is to insure that materials furnished to meet the specifications will be suitable for the use for which they are intended. The value of test requirements is measured by the extent to which they fulfill this purpose.

Test requirements may be of two types—first, those which describe the properties or characteristics of a product which it is essential that it possess if it is to be suitable for a given purpose and, second, those of a restrictive nature which define characteristics which may or may not be inherent in a suitable product, and the presence or absence of which has no measurable influence on satisfactory performance.

It is evident that, so far as possible, tests of the first type only should be used in specifications. However, the selection of such tests is not always a simple matter because of the lack of sufficient data, and the situation is frequently complicated by the difficulty of eliminating tests of the second class. The latter serve no useful purpose and such prestige as they may enjoy is undeserved, but before they can be discarded it is commonly necessary to overcome the inertia due to years of unquestioned acceptance.

Unfortunately, many of the common test requirements for road materials are of the second class. Often of obscure origin and possibly developed originally for a purpose foreign to their present use, they retain their place in specifications, sometimes for lack of adequate substitutes and sometimes because of established precedent. This is particularly true of the specifications for that class of road materials known as liquid asphaltic products, of which enormous quantities are now used in the construction and maintenance of low-cost roads. Many of the tests which are used at present in specifications for these materials have been handed down from specifications for bituminous materials of an entirely different class, often semi-solid in character, which were never intended to be used for the same purposes as those to which liquid asphaltic products commonly are put in highway work to-day.

In any attempt to rationalize specifications each individual test must be carefully scrutinized to ascertain its actual value. What does the property defined by the test signify in connection with the use to which the material is to be put and how can this property be adequately controlled by use of the test? If satisfactory answers to these two questions can not be formulated, the test has no place in a specification. Many of the tests now in common use will fail when subjected to this scrutiny.

In addition to the need for selecting the tests for liquid bituminous materials on a rational basis, there has been an equally urgent need to simplify the test requirements in current use.

The lack of agreement among the various State highway departments with respect to tests and methods of testing has created a condition which has been little short of chaotic. It is unnecessary to go into details here as this has already been done.[1] It is sufficient to state that a survey in 1930 of State highway department specifications for liquid asphaltic products showed that there were in use, including all variations, a total of 119 different tests. As the practice of the different States in specifying such products varied greatly with respect to the selection of tests required, it was too often impossible to compare the specifications of two States in order to ascertain whether they were using practically the same or entirely different materials for the same type of work.

In addition to the complications entailed by the practice of specifying different tests or combinations of tests to define the characteristics of materials of essentially similar character, there also has been no general agreement regarding the test results, or test limits, which should be incorporated in specifications. The net effect of the non-uniform practice with respect to the requirements for both tests and test results has been the establishment of an unduly large number of grades of material. This has placed on manufacturers the burden either of carrying a large stock of different grades or of being prepared to manufacture, on short notice, materials to meet the wide variations required by the specifications of the different states. Naturally, this has resulted in increased expense which ultimately has been charged to the consumer.

The disadvantages of the existing situation were manifest to all concerned and as a result there was inaugurated a cooperative undertaking designed both to simplify and to rationalize specifications for liquid asphaltic materials. This cooperation involved the highway departments of the various States, the asphalt industry as represented by the Asphalt Institute, and the Bureau of Public Roads.

STATES GROUPED BY REGIONS FOR PURPOSES OF STUDY

For convenience in carrying on the cooperative program the States were divided into five groups or regions, the division being made largely on the basis of the territory served by the principal groups of producers. The States in each region are as follows:

Region No.1.—Maine, New Hampshire, Vermont, Massachusetts, Rhode Island, Connecticut, New York.

Region No. 2.—New Jersey, Pennsylvania, Delaware, Maryland, Ohio, West Virginia, Virginia, North Carolina, South Carolina, Georgia, Florida.

Region No. 3.—Michigan, Indiana, Illinois, Wisconsin, Minnesota, Iowa, Missouri, Nebraska, Kansas, Oklahoma.

Region No. 4.—Kentucky, Tennessee, Alabama, Mississippi, Arkansas, Louisiana, Texas.

Region No. 5.—North Dakota, South Dakota, Montana, Wyoming, Colorado, New Mexico, Idaho, Utah, Arizona, Nevada, Washington, Oregon, California.

As a preliminary to the cooperative simplification work it was first necessary to establish a basis for the comparison of the great variety of requirements in current use. Without such a basis of comparison there is no adequate means for establishing the value of present and proposed tests nor for comparing the specifications of one State with those of another, even for materials which may be essentially the same.

[1] Cooperative Research and Standardization of Low Cost Road Improvement, by Prevost Hubbard, Eighth Annual Asphalt Paving Conference, 1929. Simplified Specifications for Liquid Asphaltic Materials, by E. F. Kelley, Ninth Annual Asphalt Paving Conference, 1930. Cooperative Simplification of Tests and Specifications of Liquid Asphaltic Materials, by J. T. Pauls, Association of Asphalt Paving Technologists, January, 1932.

SIMPLIFIED SCHEME OF ANALYSIS ADOPTED

To furnish this basis of comparison a definite test procedure for the examination of all liquid asphaltic products was proposed. This procedure, known as the simplified scheme of analysis, was designed to reduce the required number of tests for any product to a minimum and the attempt was made to select the tests on a rational basis so that, by proper selection, they would define the essential characteristics of all materials of this general class.

Meetings, which were attended by representatives of the cooperating agencies, were held in the five regions early in 1931 for the purpose of considering the proposed simplified scheme of analysis and to formulate a program for the future conduct of the cooperative work.

As a result of these meetings the scheme of analysis was modified in some of its details and adopted for use in the investigation, for which a program was drawn up. This investigation was for the two-fold purpose of studying the adequacy of the scheme of analysis and developing data which would permit a comparison of different specifications and the materials furnished to meet them. The program provided:

(*a*) That the producers should submit to the State highway departments samples of their products which would meet State specifications in which they were interested commercially. Two samples, varying as much in consistency as possible while still complying with all specification requirements, were to be submitted.

(*b*) That each sample should be tested, by the producer and by the department to which it was submitted, in accordance with the requirements of the State specifications and also in accordance with the approved scheme of analysis.

(*c*) That each State highway department should test, both according to the approved scheme and for compliance with its own specifications, a sufficient number of deliveries of materials purchased for use to cover the range in characteristics likely to occur in each type of material.

The cooperative work contemplated in this program was begun immediately after the regional meetings and was actively prosecuted until its completion late in the year 1931. In connection with this work the producers submitted to the State highway departments 1,154 samples of liquid asphaltic road materials. These samples were furnished by 27 producing companies from 47 refineries. In some cases a particular product complied with the requirements of several States so that with respect to the number of different materials there were some duplications. Eliminating such duplications, the samples submitted represented 715 different products produced to meet approximately 200 State specifications for all grades of liquid asphaltic materials used throughout the United States. The samples were all tested by the producers prior to shipment and a large percentage of them were tested by the highway departments to which they were sent. Thus, in addition to the basic data which were desired, there were made available a great number of check tests on duplicate samples of the same material and, in the cases of the duplication of materials mentioned above, check tests on the same materials by several laboratories. In addition to the tests made on samples furnished by producers, the State highway departments reported tests on 361 shipments of materials purchased for use.

The cooperative program provided that the producers should furnish to the Bureau of Public Roads, for such tests as might be considered necessary, duplicates of all samples of materials sent to the State highway departments. It also provided that copies of all test results should be sent to the bureau by the producers and by the States.

These duplicate samples were received by the bureau but were not tested. The samples will be retained for a reasonable period for possible use in connection with questions which may arise later.

The test reports were received by the bureau from time to time during the summer and fall of 1931. Late in the year, as the testing work neared completion, all of the data which they contained were placed in tabular form and distributed for the information of the cooperating agencies. The data contained in these tabulations give additional emphasis to the need for rationalization and simplification of the specification test requirements.

CLASSIFICATION OF MATERIALS BASED ON VISCOSITY AND DISTILLATION TESTS

The simplified scheme of analysis which has been followed in the cooperative work embodies two tests which are considered to be of major importance. These are the viscosity test and the distillation test. The viscosity test is made with the Saybolt-Furol viscosimeter at one of three selected temperatures, depending upon the character of the material and its intended use. The distillation test is included in the scheme of analysis to take the place of tests for determination of asphalt content and loss by volatilization at different temperatures. The residue from the distillation test is subjected to tests for consistency and solubility in carbon disulphide, replacing similar tests frequently made on original materials or on residues from the volatilization and asphalt content tests.

In tabulating the data obtained in the cooperative tests, the materials were classified as to type on the basis of these two important tests.

The materials were first divided into three classes, depending upon the consistency of the residue from the distillation test, as follows:

1. Liquid residue (float test less than 25 seconds at 122° F.)
2. Float residue (float test more than 25 seconds at 122° F. and penetration more than 300 at 77° F.).
3. Penetration residue (penetration less than 300 at 77° F.).

Each of these classes was further subdivided on the basis of viscosity, as follows:

A. Viscosity, Furol, determined at 77° F.
B. Viscosity, Furol, determined at 122° F.
C. Viscosity, Furol, determined at 210° F.

The nine types of material which result from this classification are shown in the following table:

Character of residue	Viscosity, Furol, at—		
	77° F.	122° F.	210° F.
1. Liquid	1–A	1–B	1–C
2. Float	2–A	2–B	2–C
3. Penetration	3–A	3–B	3–C

It is evident that materials of types 1–A, 1–B, and 1–C are of the nonhardening or extremely slowly hardening variety and, irrespective of their original viscosities, could not be expected to develop an asphalt cement in place in a road surface. Materials of types 2–A, 2–B, and 2–C yield a distillation residue too soft for a penetration test, but sufficiently viscous for a float test and therefore would be classed as slowly hardening products whose consistency might increase materially after application, but which could not be expected to develop an asphalt cement in place. Materials of types 3–A, 3–B, and 3–C, yielding a distillation residue sufficiently hard for a penetration test, would be classed as products which will eventually develop an asphalt cement in place, the rapidity of hardening being indicated by the results of the distillation test.

A study of the tabulated data, which included also State specification requirements for the various materials, showed clearly that many specifications in common use do not make the important distinctions of the above classification. In a number of cases several materials of entirely different type were found to meet all the requirements of a given specification. For instance, it was found that certain materials of types 1–A, 2–A, and 3–A were submitted to meet the requirements of a specification for a certain material designated as 45 per cent asphaltic oil. The essential requirement of this specification was that the material should contain between 45 and 55 per cent of residue of 100 penetration. The three distinct types met this specification except that the material of type 3–A had an asphalt content slightly above the maximum specified. The specification failed so far in defining important characteristics, that materials which developed liquid residues, float residues, and possibly penetration residues in the distillation test could all comply with its requirements.

The tabulated data with respect to specifications showed clearly the necessity for discarding many tests in current use if any simplification is to be effected. As an example, in one region the 51 specifications for liquid asphaltic products required a total of 44 different tests.

Early in 1932 a second series of regional meetings was held to consider the data which had been developed by the cooperative tests and to obtain an expression from the States on the adoption of the proposed simplified scheme of analysis for use in future specifications and the elimination of other tests which might be considered unnecessary.

The proposed scheme of analysis has been modified slightly with respect to certain details in the method of making the distillation test, and the test for solubility in naphtha, which had been added to the original scheme in the first series of regional meetings, was eliminated by the majority of the States represented at the second series of meetings. Aside from these changes the simplified scheme of analysis, as considered at the second series of regional meetings, is substantially the same as the scheme in its present recommended form, which is given in the following paragraphs.

RECOMMENDED SIMPLIFIED SCHEME OF ANALYSIS FOR USE IN SPECIFICATIONS FOR LIQUID ASPHALTIC ROAD MATERIALS

1. Flash point:
   - *a.* Cleveland open cup for materials having a flash point of 175° F. or more. A. S. T. M. standard method D 92–24.
   - *b.* Tagliabue open cup [2] for materials having a flash point of less than 175° F. Method approved by the Bureau of Explosives, 30 Vesey Street, New York City, and by the Interstate Commerce Commission (Regulations for Transportation of Explosives, etc., par. 227).
2. Consistency:
   - A. Viscosity, Furol, A. S. T. M. standard method D 88–30.
     - *a.* At 77° F. for dust layers, primers, and all products which are applied without warming.
     - *b.* At 122° F. for all products, including cut-backs, which are warmed slightly before application.
     - *c.* At 210° F. for all highly viscous products which must be heated to approximately 200° F. or above before application and which have a viscosity of less than 300 seconds at this temperature.
   - B. Float test at 122° F. on materials having a viscosity, Furol, of more than 300 seconds at 210° F. A. S. T. M. standard method D 139–27.
3. Distillation—for all products:

   Total distillate, by volume, at the following temperatures: 437° F., 600° F., 680° F.

   A. S. T. M. standard method D 20–30 with the following modifications:

   Sample distilled shall be 200 cubic centimeters, the weight of this volume to be calculated from the specific gravity at 60° F.

   Bulb of thermometer shall be immersed to a point one-fourth inch above bottom of flask.

   Condenser shall be water cooled.

   Distillate shall be collected in 100-cubic-centimeter graduated glass cylinders and the amount of distillate shall be reported in percentages by volume of water-free material.

   Distillation shall be stopped at 680 °F. and the amount of distillate read to the nearest cubic centimeter after the condenser has been allowed to drain thoroughly into the receiver. The total residue shall then be poured immediately into an 8-ounce tin and allowed to air cool without covering to a temperature below its fuming point suitable for pouring. It shall then be stirred and poured into proper receptacles for additional tests.

   Temperatures observed in the distillation test shall be corrected for the effect of the altitude of the laboratory in which the test is made. (See A. S. T. M. standard method D 86–30.)
4. Tests on residue from distillation:
   - *a.* Float test at 122° F. on all residues having a float of more than 25 seconds at this temperature and having a penetration of more than 300 at 77° F. (100 grams, 5 seconds.) A. S. T. M. standard method D 139–27.
   - *b* Penetration at 77° F. on all residues of less than 300 penetration (100 grams, 5 seconds). A. S. T. M. standard method D 5–25.
   - *c.* Ductility at 77° F. on all residues of less than 200 penetration at 77° F. (100 grams, 5 seconds). A. S. T. M. tentative method D 113–26T.
   - *d.* Solubility in carbon disulphide—all residues. A. S. T. M. standard method D 4–27.

[2] Method of test for flash point with Tagliabue open cup: The Tagliabue open cup flash tester shall be used. The instrument shall set firm and level.

Fill the metal bath cup with water having a temperature at least 20° F. below the probable flash point of the oil to be tested, leaving room for displacement by the glass oil cup, which is then placed in the bath.

Fill the glass oil cup with the oil to be tested to within five-sixteenths inch of its upper level edge. See that there is no oil on the outside of the cup, or upon its upper level edge, using soft paper to clean the cup.

Adjust the horizontal flashing-taper guide-wire in place. Suspend the thermometer, with its bulb well covered by the oil. Heat bath with small flame lamp having the flame so adjusted that it will raise the temperature of the oil at a rate of 2½° F. per minute, without removing the lamp during the whole operation.

For viscous liquids it is necessary that the liquid be stirred at intervals during the test.

Remove air bubbles, if any, from the surface of the oil before first trial for flash is made.

At the proper trial temperatures, noted below, try for flash with a small bead of flame (not over one-eighth inch) by drawing it quickly and without pause across the guide wire from left to right.

The temperature at which the first or initial flash is obtained is called the flash point.

Trial temperatures: For materials which may be expected to flash at about 80° F., try for flash at 70° F., then at 75°, 77°, 79°, 81°, 83°, and 85°. For other materials try for flash first at a temperature about 20° F. below the expected flash point and then try for flash at every 5° F.

MUCH PROGRESS MADE AT REGIONAL MEETINGS

The discussions which took place at the second series of regional meetings related entirely to the adoption or elimination of test requirements and no attempt was made to set up test limits for specification purposes. The action taken at the meetings was quite informal in the sense that the acceptance or rejection of a test by a State was considered to represent the intent of that particular State with respect to its own specifications and the action of a majority was not considered as binding on the minority.

The important accomplishments of these meetings, which were attended by representatives of 30 of the 48 State highway departments, are summarized as follows:

The adoption of the tests for flash point, as given in the simplified scheme, was practically unanimous, as was also the adoption of the Saybolt-Furol viscosity test to replace the Engler test. With few exceptions it was agreed that the temperatures at which viscosity determinations would be made would be 77° F., 122° F., and 210° F. It was also generally agreed that the float test at 122° F. would be used for materials having a viscosity, Furol, of more than 300 seconds at 210° F.

With two exceptions, the distillation test as described was adopted for cut-back materials by all the States represented, but the majority were not prepared at present to extend its use to materials other than cut-backs. A number announced the intention of making a further study of its suitability for the materials not classed as cut-backs. Discussion of this question led the representatives of the States in region No. 3 to define cut-backs as follows: Cut-back asphalt is a liquid asphaltic product which, when distilled to 680° F., yields a residue of less than 300 penetration at 77° F.

It was generally agreed that the end point of the distillation test should be 680° F. and that the volume of distillate should also be determined at 437° F. and 600° F. One region agreed to use no other temperatures. One region added another cut at 374° F.; another made the use of this temperature optional; and the other two regions added to it the temperatures of 302° F., 320° F., and 500° F., with the general agreement that not more than four temperatures in addition to that of 680° F. would be used in any one specification.

The agreement to adopt the proposed tests of residues from the distillation test was practically unanimous.

With respect to the elimination of tests not included in the simplified scheme of analysis, there was less unanimity of opinion than in the case of the tests included in the scheme, but, in spite of this, considerable progress was made.

As has been noted, the agreement to replace the Engler with the Saybolt-Furol viscosimeter was practically unanimous and only a small minority expressed the intention of retaining the test for insolubility in naphtha. However, a large majority favored the retention of the test for the determination of asphalt content, particularly for materials other than cut-backs, until such time as it is more definitely established that the tests in the simplified scheme are adequate to replace it. A large number of those who favored the continued use of the asphalt content test also favored a ductility test on the residue.

About half the States represented at these meetings will continue to use the volatilization test (loss on heating for five hours at 325° F.) for the time being, at least, although of these about half will use it only for materials other than cut-backs. The States retaining the volatilization test generally will retain also penetration or float tests on the residues from volatilization.

The volatilization test at 212° F., which has been used to a limited extent in the past, was rejected with only one dissenting vote. The elimination of the test for fixed carbon was also practically unanimous.

The test for the determination of paraffine scale, concerning which there has been much discussion during the past few years, particularly in the States of region No. 5, received, in the various meetings, only one vote for its retention. It is known, however, that at least one other State, which was not represented at the meetings, will continue to use the test in spite of its questionable accuracy and problematical value.

The test for solubility of original materials in carbon tetrachloride will not be continued to any extent except in one region.

The vote for the elimination of specific-gravity determinations on original materials and distillates and float tests on original materials at 77° F. and 90° F. was so nearly unanimous that their continued use will be practically negligible.

This summary of accomplishment evidences a truly encouraging progress in the simplification program, particularly when one considers the relatively short time during which the cooperative effort has been carried on. However, much remains to be accomplished before the program can be brought to a satisfactory working basis. Misunderstandings and misconceptions must be cleared up and a more complete knowledge and understanding of many details must be obtained. As an aid in this direction it is believed that a discussion of the logic of the proposed simplified scheme of testing and a critical analysis of other tests still in common use in certain regions will be of service.

ESSENTIAL PROPERTIES TO BE DEFINED IN SPECIFICATIONS FOR LIQUID ASPHALTIC PRODUCTS

Without regard to the individual tests which may be used for the purpose, it seems important to specify certain fundamental properties of liquid asphaltic products, depending upon their method of use and the purpose which they are expected to serve. Of these, the most important appear to be:

1. Original consistency.
2. Ultimate consistency as representing the material developed after application.
3. Relative rapidity of the change, if any, from original consistency.
4. Amount and character of active bitumen remaining after application.

Original consistency.—The determination of consistency of the original material is essential and, in the case of liquid asphaltic products, it is commonly ascertained by a test for viscosity. Some form of viscosity test almost invariably has been incorporated in specifications for materials of this character. The method chosen for determining viscosity of highway materials usually has involved the use either of the Engler viscosimeter or of the Saybolt-Furol viscosimeter, the test being made with each instrument at a variety of temperatures ranging from 77° F. to 212° F.

As has been noted, the decision to substitute the Saybolt-Furol test for the Engler test in the simplified scheme of analysis was practically unanimous and it was generally agreed to make the viscosity determinations at temperatures of 77° F., 122° F., and 210° F. The primary reason for the selection of the Saybolt-Furol instrument in preference to the Engler is the considerably shorter time which is required for the test. The availability of apparatus with multiple tubes and an accurate, automatic temperature control are added advantages of the Saybolt-Furol test.

The maximum temperature originally proposed for the viscosity test was 212° F. (100° C.), but this was changed to 210° F. to eliminate the general need for the use of an oil bath instead of a water bath. The difference between the two temperatures is not particularly important, but the advantage, if any, gained by the change to 210° F. is not general, since in laboratories located at altitudes much over 1,000 feet above sea level the oil bath must be used for either temperature.

The viscosity, or resistance to flow, of all liquid bituminous materials may be decreased by raising their temperatures, but the decrease in viscosity per unit rise in temperature often varies greatly for different products. Therefore, a given viscosity value at an elevated temperature, such as 212° F., by no means indicates the viscosity or consistency of the product at a more normal temperature.

Consequently, it is desirable when possible to ascertain the consistency of bituminous road materials at what may be considered a normal temperature. Since 77° F. has been accepted generally as an average normal temperature, it is desirable to make the viscosity test at this temperature when it is possible to do so satisfactorily. However, many of the liquid asphaltic products are so highly viscous that a satisfactory determination at 77° F. can not be made. In such cases it is necessary to make the test at some elevated temperature, and this preferably should be within the range to which the material may be subjected in service subsequent to its application. A temperature of 140° F. represents the approximate maximum of this range. Many materials which are too viscous to be tested at 77° F. may be tested accurately at 122° F., and this test temperature, which is within the service range, has come into quite general use for such products. In the proposed simplified scheme of analysis, therefore, 77° F. and 122° F. were put forward as being satisfactory temperatures for the great bulk of products now in use.

Some products so nearly approach the semisolid state in original consistency at normal temperatures that satisfactory viscosity tests can not be made on them even at a temperature of 140° F. or considerably higher. For such products the temperature of 210° F. has been adopted. As a result of further consideration of the matter and subsequent analysis of the cooperative test data, it now appears that it might be advantageous to eliminate determinations of viscosity at this high temperature and substitute the float test at 122° F. as a measure of consistency of those products which can not be tested for viscosity at 122° F.

It seems highly desirable to control the consistency of all materials by tests at temperatures within the range of those encountered in service subsequent to application. At the present time the float test appears to be the only acceptable test which is satisfactory for such determinations when the material is too viscous for a viscosity test and too soft for a penetration test within this range of temperature. While it can not be translated accurately into terms of viscosity or penetration for all types and grades of asphaltic material, nevertheless it gives an idea of approximate consistency which is far more significant than a viscosity test at 210° F.

As has been stated previously, the viscosity at 210° F. or 212° F. does not indicate consistency at normal temperature, and from the standpoint of the application of a material no record of viscosity at such an elevated temperature appears necessary. For all practical purposes, therefore, it is believed that the float test at 122° F. will be satisfactory as a measure of consistency of the class of materials which are too viscous for a viscosity test at 122° F. and too soft for a penetration test at 77° F.

Ultimate consistency as representing material developed after application.—In certain types of highway construction and treatment, liquid asphaltic materials are used in preference to the semisolid varieties to facilitate their application to or manipulation with the nonbituminous constituents of the roadway surface. If it were practicable to use a much more viscous product, such a product frequently would be used preferentially to produce without delay the results which it planned to secure ultimately. In other words, while not invariably so, it is frequently desirable that the viscosity or consistency of the original material should become greater after it has been applied. Therefore, it is desirable to ascertain and properly describe in specifications the approximate degree to which the original material will harden or increase in viscosity after use. Various tests have been used with this general purpose in mind, but comparatively few actually give the desired information for reasons which will be discussed later. Before the simplified scheme of analysis was proposed, these tests were carefully considered from all standpoints and it was concluded that the distillation test, with the thermometer bulb in the liquid rather than in the vapor phase, came nearer to giving the desired information than any other single test.

A distillation test carried to an end temperature of 680° F. has been used for some years by a number of the State highway departments in the testing of cut-back asphalts. The definition of a cut-back, which consists of an asphalt cement fluxed to fluid consistency with a volatile distillate, has been given. Such products, when exposed in relatively thin films, are known to revert to the approximate consistency or penetration of the original asphalt cement through loss by volatilization of the solvent. In order to remove the solvent rapidly by distillation it is necessary to carry the distillation to 680° F. In the case of cut-back asphalts, therefore, in order to determine the approximate consistency which the original material may be expected to attain, after application, the material is distilled to 680° F. and the penetration of the residue remaining after distillation is taken as an indication of the increase in consistency which may be expected to occur under conditions of use.

Since cut-back products tend to harden through the loss of volatile constituents which are removed as distillates in the distillation test, it seems reasonable to believe that the test is as applicable to the liquid asphaltic products of other types, and that a determination of consistency of the residue obtained from distillation will serve as a reasonably accurate measure of the degree of hardening which any such product may be expected to undergo after application.

The penetration test at 77° F. is a satisfactory measure of consistency where it can be used, but many of the liquid asphaltic products which have proved adequate for certain purposes will not yield a distillation residue sufficiently hard to be subjected to the penetration test. For such residues, therefore, the float test at 122° F. has been included in the simplified scheme of analysis. This permits the rating of consistency of residues as liquid if the float test is less than 25 seconds; by float test if this exceeds 25 seconds and the penetration is more than 300; and by the penetration test if the penetration is less than 300.

Rate of change in consistency.—In many types of construction the rate of change in consistency after use is important and it is desirable to have a knowledge of the probable rapidity with which this change will take place and also to have a means for its approximate control. Here again the distillation test proves superior to other tests which have been used, since it permits the determination of the percentage of volatile materials which distill off at temperatures intermediate between the initial boiling point and the final test temperature of 680° F. The value of the distillation test in this connection has already been demonstrated in its application to cut-back asphalts. By the proper selection of temperatures and corresponding percentages of distillate the rate of change in consistency can be controlled within reasonable and practicable limits. Probably not more than three temperatures at properly spaced intervals will be required to give the necessary information. In the simplified scheme of analysis the temperatures which have been proposed are 437° F., 600° F., and the end temperature of 680° F. These temperatures should be sufficient for road oils and slowly hardening cut-backs, but for quickly hardening cut-backs an additional lower temperature, possibly 374° F., may be required.

Amount and character of active bitumen remaining after application.—In addition to obtaining the change in consistency of a material by measuring the consistency of the residue from the distillation test and ascertaining the relative rapidity of the hardening process, the distillation test also makes it possible, by recording the volume of residue, to determine the amount or percentage of the final product in terms of the original material.

Other characteristics of the residual bitumen, in addition to its amount and consistency, are of interest. Thus, its freedom from admixture with foreign substances can be readily obtained by the test for solubility in carbon disulphide, which has been included in the proposed scheme of analysis. It is suggested that the test for solubility in carbon tetrachloride may be even more useful since it is indicative of all the information furnished by the carbon disulphide test and, at the same time, it may assist in differentiating between materials produced by straight distillation or mild cracking and those produced by severe cracking processes, which may have characteristics approaching those of tar.

For residues which would be classed as asphalt cements and which are sufficiently hard to have a penetration of less than 200 at 77° F. it was considered desirable to include, in the scheme of analysis, a test for ductility of the residue at 77° F.

FLASH POINT TEST ESSENTIAL AS SAFETY MEASURE

In addition to what are believed to be essential tests, one other test may legitimately be included in the simplified scheme of analysis, namely, the flash-point test.

Certain classes of asphaltic road materials containing a very volatile distillate may flash at relatively low temperatures. The regulations of the Interstate Commerce Commission governing the rail shipments of such materials require that the flash point be determined with the Tagliabue open cup and that materials which flash at a temperature of 80° F. or less be identified by a special label. Accordingly, the use of the Tagliabue open cup has been specified in the simplified scheme of analysis for materials of low flash point and the method of test approved by the Bureau of Explosives has been adopted.

In addition to a flash point test to determine compliance with shipping regulations, it is desirable, from the standpoint of safety, to limit the minimum flash point of materials which are to be heated before application. For materials flashing at 175° F. or higher the test with the Cleveland open cup (A. S. T. M. standard method D 92–24) has been adopted. Since this method restricts the test to a minimum temperature of 175° F., this temperature has been made the upper limit for flash point determinations with the Tagliabue instrument.

TESTS OF QUESTIONABLE VALUE

We have discussed the tests included in the simplified scheme which are believed to be essential for defining desirable properties of liquid asphaltic products for highway use. A critical examination of other tests which are commonly employed in the specifications for such products is in order. In the 1932 series of regional conferences quite general agreement was reached by the representatives of the State highway departments regarding the advisability of eliminating such tests as specific viscosity (Engler), specific gravity, fixed carbon, paraffine scale, and float test on original material at other than 122° F., and therefore further discussion of these tests is unnecessary.

Tests for asphalt content or residue of a given penetration.—Probably no single test has become more firmly established in specifications for liquid asphaltic products than that for the determination of percentage of residue of a given penetration, commonly known as the asphalt content of the product. A general feeling seems to prevail on the part of highway chemists and engineers not only that the amount of such residue indicates the degree of asphaltic character possessed by the material, but also that in some way the actual percentage of asphalt content measures the serviceability of such products for highway purposes. While no direct claim is made that if a product develops a given percentage of asphalt content by this test, it will develop such asphalt in place after use, the feeling prevails that in some way or other such is the case, and so the liquid asphaltic products frequently are graded on the basis of their so-called asphalt content.

The test is made by maintaining a weighed sample exposed to the air in an open receptacle at a temperature of 480° to 500° F. for whatever period of time is required to reduce it to the specified penetration, usually either 100 or 80 penetration at 77° F. No experimental data have ever been made available to show that the residue so obtained is even approximately reproduced when the material is subjected to service conditions, while there are excellent reasons which indicate that such can not be the case except, perhaps, for cut-back asphalts. However, the test is not generally applied to cut-backs, since the distillation test has come to be recognized as giving much more accurate information relative to the probable behavior of such materials after application.

The reasons why the asphalt content test does not give information as to the character of material developed after application are as follows:

(1) It is a well-known fact that asphaltic materials, when subjected to the temperatures at which this test

is conducted, are, as a rule, highly susceptible to oxidation, and that oxidation over the period of time required for the test produces chemical changes which are not produced at the normal temperatures encountered under ordinary service conditions. These chemical reactions result in an artificial hardening of the product, so that a residue which does not represent an actual residual constituent of the original material is manufactured by the test itself.

(2) Even if the residue of given penetration actually existed in the original material, no service conditions would be sufficiently severe to develop this residue in place except possibly in a thin film on the highway surface. Thus, many liquid residual petroleums, from which a given percentage of asphalt of a given penetration may be obtained from distillation processes as conducted in a refinery, will never develop this asphalt as such under service conditions because the oils which hold the actual asphalt in solution are nonvolatile at ordinary atmospheric temperatures and never leave the asphalt residue under conditions of use.

In view of these facts, the question at once arises as to what purpose an asphalt residue serves, even when present, if it is never allowed to develop as an asphalt cement. Certainly it can not develop high binding value because no liquid asphaltic product which does not harden can be shown to possess high binding properties any more than can any permanently liquid glue. Hardening is necessary to develop binding properties and it is therefore of far greater importance to determine the probable change in consistency or hardening of the material after use than it is to determine the amount of material of a given hardness which can be obtained only by artificial means which are not duplicated by conditions of service.

It has already been pointed out that the distillation test is capable of indicating the probable degree of hardening that the material may be expected to reach after application to or incorporation with the mineral aggregate. However, quite a few engineers and chemists, who have come to depend upon the asphalt content test, feel that the distillation test does not always give them the information which is desired because of the fact that many liquid asphaltic products, which will yield a relatively high asphalt content, often show little loss by distillation to 680° F. and yield a distillation residue which is still fluid. It has been pointed out that if, upon distillation, a liquid residue remains, the product can not be expected to develop an asphalt cement after application. So long as the asphalt cement which may exist is held permanently in solution, it appears to be quite immaterial what the exact percentage of such asphalt cement may be.

It would seem, therefore, that the asphalt content test might well be abandoned altogether for use in specifications, together with such tests on the resulting residue as are sometimes specified. In this connection, particular reference is made to requirements for ductility of residue of a given penetration since the physical properties of the residue will vary, depending upon the temperature at which the residue is produced and the length of time it is exposed to the oxidizing action of air at that temperature.

Volatilization loss at 325° F. and 212° F. and tests on residues.—Determination of loss by volatilization at 325° F. and consistency of the resulting residue are tests which originally were devised for asphalt cements and fluxes in connection with their use in hot asphalt paving mixtures. In the preparation of such mixtures the asphaltic constituents are customarily maintained at a temperature of approximately 325° F. over rather long periods of time and the mineral constituents of the mixture are also heated to approximately this temperature. Therefore, it is quite logical to make the tests on these products in connection with such use for the purpose of determining loss by volatilization and the degree of hardening that may be expected to occur during manipulation.

As the use of the liquid asphaltic products was developed for low-cost road construction, it became rather customary to utilize the volatilization test at 325° F. in specifying such products, merely because it had been used extensively in connection with materials for hot-laid asphalt pavements. Apparently no thought was given to the fact that many of these liquid products were never heated to the temperature at which the test was run and were, in most cases, applied to or incorporated with unheated mineral aggregate. In reality, therefore, there is little excuse for applying this test to liquid asphaltic products except when it is intended that they shall be used as permanent fluxes for harder asphalts.

It is true that, in the case of products which may be expected to increase in consistency or harden after use, appreciable quantities of volatile constituents are driven off during the test and that a determination of the consistency of residue will indicate some degree of hardening. However, the test is run at the maximum temperature for such a long period of time that it does not in any way reproduce service conditions. At best, no indication of rapidity of hardening is given by the test results, such as is very definitely shown in the distillation test by the percentage of distillate obtained at various temperatures between the initial boiling point and the end-point of distillation. This fact has been recognized by some testing engineers who accordingly have utilized a volatilization test at 212° F. in addition to the test at 325° F. The relative difference in loss and in consistency of residues from the tests at these two temperatures tend to establish some relation between the rate of hardening of different products, but here again the information is not nearly as complete or reliable as that given by the distillation test. Therefore, it appears that all of the tests for loss by volatilization and tests on the consistency of the residues so produced could well be abandoned in favor of the distillation test which, at least for cut-backs, has demonstrated its direct relation to the behavior of the material after application.

Bitumen insoluble in naphtha.—In spite of the very considerable amount of study which has been devoted to the subject, the chemical composition of asphalts is but little understood. Their predominating constituent is bitumen, which is completely soluble in carbon disulphide. By treating an asphalt with a naphtha of low boiling point it is possible to precipitate a portion of the bitumen in the form of a dark brown or black powder which may be separated by filtration. These insoluble constituents have been called asphaltenes. Asphaltenes are complicated mixtures of hydrocarbons, the exact function of which, in an asphalt, is not thoroughly understood. All asphalts contain such constituents, but the percentage varies greatly with the character of the naphtha, such as its gravity and range of boiling points.

When asphalts from only a few individual sources were commercially available for highway work and when asphaltenes in these particular asphalts were found to lie within fairly narrow quantitative limits, it became customary to include in specifications the test for bitumen insoluble in naphtha. The determination itself served as no direct insurance of quality of the product but rather as a descriptive test.

Later, as asphalts were developed from numerous other sources, it became apparent that the percentage of asphaltenes which they contained varied within wide limits but that such variation had no direct traceable relationship to the relative behavior or serviceability of these products. Moreover, it was learned that the percentage of asphaltenes in an asphalt obtained from a given source could be increased materially by subjecting the material to oxidation by the blowing process. Since no definite relationship between desirable properties of an asphalt and its asphaltene content could be established, the test was gradually eliminated from specifications for asphalt cements although, for no apparent good reason, it is still retained to a limited extent in certain specifications.

Its application to liquid asphaltic products, however, has become quite general in certain sections of the country due to an opinion that in some way the percentage of asphaltenes indicates the asphaltic character of the product. It is true that those petroleum products which contain but little asphalt in solution show a very low percentage of asphaltenes, but, because of the tremendous variation in percentage of asphaltenes in satisfactory asphalts from different sources, it is apparent that wide variations will occur in liquid products which contain appreciable quantities of these asphalts in solution. The percentage present in a given product therefore can hardly be expected to indicate the suitability of the product for a given use.

Many of the State highway departments have agreed to the elimination of this test from specifications, and it is hoped that unanimous agreement upon elimination will ultimately be reached. At best, the test is exceedingly inaccurate and subject to wide variations in the results obtained by different operators. This is due not only to the difficulty in standardization of the naphtha solvent but also to the fact that the solvent is constantly changing in composition through partial volatilization during the filtration process and the further fact that there is no clear end point for separation of soluble from insoluble material. The filtrate shows discoloration even after prolonged washing of the precipitated asphaltenes on the filter bed. Probably no other test which has been applied to asphaltic products can be less easily checked by different operators than the test for bitumen insoluble in naphtha, and this fact alone should be sufficient for its elimination from specifications.

Test requirements for original components of blended or cut-back products.—In specifications for blended products such as cut-back asphalts some State highway departments, in addition to the requirements for the finished product, include also detailed requirements both for the original asphalt cement and the original distillate to be used in the manufacture of the product. Such practice is believed to be unnecessary, since it is doubtful if it constitutes a better guaranty of quality than do properly drawn specifications for the finished product only. It may also be uneconomical since it tends to hamper the manufacturer and may eliminate desirable competition.

If specifications for a cut-back product cover its original consistency, the consistency and character of its residue from the distillation test, and the rapidity with which it may be expected to develop this residue after application, it is immaterial just how it has been manufactured. Practically the same finished product often may be produced from a variety of individual constituents and this fact is clearly recognized in specifications for other materials, as for example, Portland cement, in which no attempt is made to specify the exact nature of the original argillaceous and calcareous constituents from which it is manufactured.

In the petroleum industry the production of distillates is of major importance and the manufacture of cut-back asphalts constitutes a very small part of the business. In the production of these distillates, crude oils from a great many sources are refined by a variety of processes and probably no two refineries employ exactly the same refining processes on the same crude oils. Moreover, their markets for distillate products vary considerably, so that all do not produce the same standard distillates. Before many of these distillates are placed on the market they are subjected to expensive treatments to improve their color and odor, which characteristics are immaterial from the standpoint of use in the manufacture of cut-back asphalts. Unfinished distillates, therefore, are often the most economical to use in such highway materials, and it would often be impractical to rearrange refinery practice to produce a special specification distillate for the relatively limited use it would have for such products.

Paving asphalts, on the other hand, have become well standardized products manufactured in a definite number of grades ranging from very hard to very soft. In general, the only difference between these grades is the extent to which the original crude petroleum, from which they are obtained, has been distilled. In other words, the harder varieties may be produced from the softer ones by distilling off a small amount of oil from the latter. It follows therefore that the softer grades may be produced from the harder by fluxing the latter with a high-boiling distillate oil similar to that which was removed in reducing them from the softer consistency to their original degree of hardness.

Many unfinished refinery distillates available for producing cut-back asphalts contain a small amount of high-boiling oils similar to those which would be removed in converting a soft asphalt to one of harder consistency. When present in a cut-back asphalt this portion of the original refinery distillate remains in the residue from the distillation test and, therefore, serves as a permanent flux for the asphalt cement used in the preparation of the cut-back. The asphalt cement recovered from the distillation test is, therefore, of softer consistency than the asphalt originally used.

Specifications for the finished product require that the residue from the distillation test shall be within certain limits of consistency which are considered essential from the standpoint of behavior after use. Provided this requirement is met, it is apparent that, so far as the consumer is concerned, it is immaterial whether the original cut-back is made with a relatively soft asphalt fluxed with a distillate which will be completely removed by the distillation test, or with a relatively hard asphalt fluxed with a distillate containing a high-boiling fraction which is not removed by the distillation test but which permanently reduces the hard asphalt to the consistency specified for the residue.

These relations, which are of great importance to the manufacturer, are clearly illustrated in the diagram of

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THE BATCHING PLANT IN CONCRETE PAVING WORK

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THE BATCHING plant, the primary purpose of which is to supply the hauling units with the materials which they are to carry to the concrete mixer, is an essential part of the auxiliary equipment necessary to the efficient functioning of the customary portable paving outfit. In these outfits the paver or mixer is the key producer with which all equipment, operations and procedures must be properly coordinated in order to produce high operating efficiencies and low unit costs. This is due to the fact that the rate at which such a paving outfit can produce square yards or cubic yards of finished concrete pavement is definitely fixed, first, by the time required to pass the specified batch through the mixer, and, second, by the extent to which this operation can be maintained with clocklike precision as a continuous performance. It is this factor of maintaining steady, continuous operation which is so difficult.

Figure 1.—A Three-Compartment Bin and the Effective Use of Planks Greatly Reduces the Amount of Space Necessary to Handle Two Sizes of Aggregate

While it is true that no matter how large or how well the outfit is equipped, organized, and managed, the rate fixed by the characteristics and requirement of the mixer can not be exceeded, it is equally true that no necessary or prescribed operation or requirement is so trivial or so insignificant that it can not delay or hold up production just as effectively as though for the time it were the sole essential factor. Every piece of equipment, every group or assembly, must therefore be able to perform its required function with the regularity and within the limits set by the mixer; otherwise a loss in production is the unescapable penalty. This applies with particular emphasis to the batching plant through which all the principal raw materials must pass.

The three essential functions of the batching plant or loading yard are: (1) To receive the incoming stone or gravel, sand and cement, and provide for these such storage as may be necessary or desirable to iron out the fluctuations of the incoming supply so that the continuous demands of the mixer may be met; (2) to form or combine these materials into unit quantities of the size and the proportion required for the batch at least at the rate and with the regularity demanded by the mixer; and (3) to provide for the transfer of these batches or unit quantities into the hauling units with the least possible delay or interruption to the primary function of the trucks, which is to transport the batched materials from the loading yard to the mixer.

The usual batching plant for supplying a 27E paver capable of producing at a maximum rate of from 45 to 55 batches, or from 50 to 70 cubic yards of concrete per hour, consists essentially of a crane with a 1 or 1¼ yard bucket, one or two bins equipped with batch-weighing devices, and a cement loading platform or a cement bin, all generally located at a railroad siding where there is room for ample stockpiles; and if sack cement is used there must usually also be room for a cement shed with a capacity of at least one day's supply.

Figure 2.—Two Bins With Straight Drive Through Both. Stock Piles on Opposite Sides of Track. Crane Working on a Ramp Made of Coarse Aggregate

The function of the crane is to unload materials from cars to bins and to stockpiles and in the absence of cars to supply the bins from the stockpiles. It should in general have a capacity of not less than 1 or 1¼ cubic yards and be capable of maintaining a regular cycle of not to exceed 25 seconds per load from stockpile to bin when working on an angle of about 90°. From cars to bins the crane should be able to maintain an average cycle of not to exceed 30 seconds. Such a crane should easily be able to keep up with the mixer even at maximum production if permitted to work the coarse aggregate from cars to bins.

Table 1 shows the average rate of operation, on 10 jobs, of cranes in good condition, equipped with 1¼-yard buckets.

Table 1.—*Crane operation, unloading cars to bins—Averages for 10 jobs—1¼-yard bucket cranes, in good mechanical condition*

	Sand	Gravel
Load bucket, seconds	7.8	8.3
Swing, seconds	8.0	8.4
Dump, seconds	2.2	2.1
Return swing, seconds	7.6	7.9
Average cycle, seconds	25.6	26.7
Average angle of swing, degrees	100	112
Average load per bucket, cubic yards	.88	.76
Average number buckets per cubic yard	1.136	1.316

Average time cranes worked, per cent, 66.

If all of the materials must first go to the stockpiles, some night unloading of cars to stockpiles will probably be required when mixer production is high. Where ground conditions permit, the speed of crane operation can be increased considerably by working on a runway about 6 or 7 feet high so that the operator can see into the cars. Such a ramp and runway can be built up from coarse aggregate and used as a crane run until the last day or so of paving, when the material in the ramp is utilized as a stockpile.

Occasionally the siding is so situated that one or more pits can readily be located beneath and to the yard side of the track. The materials, shipped in dump-bottom cars, are then dumped into these pits to be taken by either a belt conveyor or the crane to the bins or stockpiles as required. This method saves some time in that the crane is not delayed by cleaning out the bottoms of the cars or in spotting new cars.

If the coarse aggregate is of two sizes, a 3-compartment bin should be used. Two bins will generally add from one-half to three-quarters minute per batch to the time constant of the trucks aside from increasing the chance for other delays to occur. The 3-compartment bin also has the advantage that it can generally be loaded by the crane more readily than the two bins where the layout is properly made and some convenient form of power unit is provided for moving the cars.

Figure 3.—Lack of Room for Ample Stock Piles and Specifications Requiring Three Sizes of Coarse Aggregate Necessitated the Use of Two Cranes

Moving the crane from one bin to the other usually consumes more time than is lost in keeping three cars within reach for loading into a 3-compartment bin. The capacity of any bin or set of bins should at least be sufficient for one hour's run of the mixer. At least this much ready storage is necessary to absorb the probable minor crane delays and interruptions which might otherwise result in somewhat similar delays to the mixer. It is much cheaper to provide this amount of reserve storage in bins than in trucks.

In the case of the cement, conditions are sometimes such that the cement bags are loaded directly from the car; but working wholly from within the car is difficult and usually it is preferable to construct a platform so that the bags can be trucked from the car and dumped directly from this platform on to the truck. For this purpose the layout must usually be studied rather carefully in order to place the cement platform so that the bags can readily be dumped from the hand trucks directly on to the waiting truck without any rehandling or moving around. To make this possible the platform must be about 6 inches higher than the truck body and so located that the trucks can readily drive very close along the side. Depressing the driveway is sometimes resorted to, but if the soil is heavy and the rainfall abundant this method is likely to prove a disappointment. The alternative is tossing the bags, one at a time, on to the truck by hand. This ordinarily requires from 10 to 15 man-seconds per bag.

The most common way of handling bulk cement at the present is in 2-wheeled buggies. These may be of either the end or bottom dumping type. This method requires a platform which should be long enough so that the unloading can proceed simultaneously from two railroad cars. This gives more room for the men to work and so increases their efficiency. For best results that part of the buggy track which extends from the platform out over the truck should be hinged at the platform edge and provided with a counter weight so that the push of the advancing buggy wheels will cause it to lower to a horizontal position but immediately return to about 75° or 80° with the horizontal as soon as the buggy has been dumped and withdrawn. A canvas boot long enough to reach the aggregate in the truck body or to reach well into the special cement container should be provided. Either the canvas of the boot or some other material should extend high enough above the boot to prevent a strong wind from whipping up the cement as it is being dumped. Table 2 gives the average results of a series of stop-watch studies of handling bulk cement in buggies.

Table 2.—*Handling bulk cement in hand buggies—All time readings in utilized man-seconds—630 pounds of cement to each buggy*

	Job 1	Job 2
Load buggy	120.7	134.7
Wheel buggy to scales	15.9	17.2
Weigh and adjust to proper weight	16.4	17.8
Wheel buggy to dumping place	10.4	10.3
Dump cement into truck	17.8	14.7
Return buggy to loaders	11.3	13.6
Total utilized man-seconds	192.5	208.3

In hot weather, loading the buggies is very trying labor. The number of shovelers must therefore be sufficient to afford frequent rest periods. On fast jobs a total of six men are usually employed on the cement in addition to the weight inspector.

The time constant of the trucks—i. e., the average total time spent by the truck during each round trip in other activities than the actual hauling of the load to the mixer and in returning again to the yard—is generally increased somewhat when bulk cement is used, the amount depending on the methods of handling the cement. Three rather general methods are in use in various sections: (1) Dumping the cement in between the aggregates, as, for example, coarse stone, sand, cement, and then second-size stone; (2) dumping cement on top of the batch and covering with a canvas or tarpaulin; and (3) carrying the cement in a special container on the truck.

Of these methods the first is generally the fastest wherever two aggregate bins are used. The cement platform or cement bin is then located between the two aggregate bins. Taking on the cement thus requires no more time than when using bag cement. The second method usually requires from 15 to 30 seconds to roll back and tie down the tarpaulin. A variation of this method is sometimes met with in which the cement is covered with a thin layer of sand or aggregate instead of with a tarpaulin. The usual procedure is to smooth off the top of the load throwing the material in a heap along the edge so that when the cement has been dumped this material is available for covering. This method usually requires two men and a delay of from one-half to one minute for each single-batch truck and about twice that amount for a 3-batch truck. The special containers used for carrying bulk cement are far from standardized. The time required to load them therefore varies with different types. In general, about 25 to 45 seconds are required for loading the cement

FIGURE 4.—HANDLING BULK CEMENT:

A.—THINGS TO BE AVOIDED IN HANDLING BULK CEMENT: PLATFORM ONLY LONG ENOUGH FOR 1 CAR; NO BOOT TO PREVENT BLOWING OR SPILLING OF CEMENT; 3-BATCH TRUCKS BUT ROOM ONLY TO DUMP 1 BUGGY AT A TIME

B.—GROUND CONDITIONS ARE SOMETIMES SUCH THAT A CONVENIENT LAYOUT IS IMPOSSIBLE

C.—THE LOADING PLATFORM FOR BULK CEMENT SHOULD ALWAYS BE LONG ENOUGH TO PERMIT WORK IN 2 CARS

D.—A WORKMANLIKE CEMENT PLATFORM, WHICH PERMITS EFFICIENT OPERATION OF THE BUGGIES AND AFFORDS AMPLE PROTECTION AGAINST BLOWING AND SPILLING

E. TWO MEN DUMPING CEMENT BUGGIES SIMULTANEOUSLY. ON THIS JOB 2-BATCH TRUCKS RECEIVED THEIR SUPPLY OF BULK CEMENT IN FROM 7 TO 7½ SECONDS

F.—A BULK CEMENT BATCHING PLANT. ON THIS JOB THE CEMENT WAS DELIVERED BY TRUCKS DIRECT FROM THE MILL

for each batch. Figures 5, A and 5, B show the layout for two yards using two bins and bulk cement. Figure 5, C shows an extremely simple layout for a batching plant using one size coarse aggregate and bag cement. Table 3 gives the yard time constants for these three layouts.

Storage of bag cement sufficient for at least one day's run should always be provided unless prompt car arrivals can be guaranteed. For a fast job this will ordinarily require a shed or platform having a floor area of about 550 square feet. Usually the storage is in the form of a shed forming a part of the regular loading platform so that the bags can readily be shifted by hand trucks from the car to the shed for storage and again, when necessary, from the shed to the batch trucks.

Equipment for the mechanical handling of bulk cement is used by many contractors. It would seem desirable that the size of the bin used with these plants be enlarged so as to provide sufficient capacity for one full day's run of cement and thus do away with the necessity of using bag cement as emergency storage. The bin should also be erected so as to permit a drive straight through and thus help to keep down the time constant or loading time of the batch trucks. The following tabulation gives the average operating characteristics of a typical cement-loading plant.

	Seconds
Fill cement hopper	17. 2
Dump cement into truck	10. 5
Average cycle	27. 7

TABLE 3.—*Yard time constants, in seconds, for layouts shown in Figure 5*

Item	Layout A		Layout B		Layout C: 2-batch trucks
	1-batch trucks	2-batch trucks	1-batch trucks	2-batch trucks	
Loading aggregates	10	68	11	70	27
Loading bulk cement and adjusting tarpaulins	33	40	33	53	
Loading bag cement					37
Driving within yard	90	110	51	59	71
Turning and backing	74	97	22	30	
Fixing batch boards		18		19	
Total net yard constant	207	333	117	231	135
Average waits and delays					15
Total gross yard constant					150
Driving distance within yard, in feet	800	800	875	875	250

The hopper could always be filled while the trucks were being exchanged so that the average time the 3-batch trucks required for taking on the cement was 73 seconds.

The loading yard must provide for the shortest and most direct possible routing of the trucks through the yard so as to detain each one as little as possible; but, above all, the yard and loading plant must provide for the maintenance of a regular uninterrupted service. Each minute added to the time the truck must spend in the yard means a cost of from 2 to about 5 cents, depending on the size of the truck and the rate paid for drivers. This charge occurs each time a truck passes through the yard. Thus, if 2-batch trucks supplying 400 batches per day to the mixer are each worth 4 cents a minute, and if the yard layout is such that to serve each truck requires an average of 2 minutes more than another layout would have required, then the loss is $16 per working day so long as this yard is used.

Costly as are the faults which increase the time required for serving the hauling units, those faults or conditions of yard layout, arrangement, or equipment which contribute to the irregularity of their operation are more to be dreaded. Any irregular delay to the trucks at the loading plant is also likely to be imposed on the mixer, and mixer delays are far more expensive. While a regular loss of truck time costs anywhere from 2 to 5 cents per minute, delays to the mixer entail a cost of about 75 cents or even $1 per minute.

Such losses are not to be looked upon lightly. In fact, an occasional delay averaging only one minute each hour to the mixer is likely to be as expensive as a regularly occurring delay of one minute to each truck loaded out of the yard. The first and most essential object of the material plant must therefore be to facilitate regular, continuous operation of the hauling units well within the time intervals set by the mixer.

The yard layout should therefore be such that, first of all, regular, continuous service can be readily maintained; second, that each hauling unit will be detained in the yard the shortest possible time interval in obtaining its load on each trip; and, third, that no regular single stop in the yard will exceed a period equal to the length of the mixing cycle multiplied by the number of batches carried by the truck. Otherwise, the yard instead of the mixer becomes the pacemaker.

Care should be taken to arrange the routing of the trucks through the yard so that there will be no interference between the various units. Since continuity and regularity of service are the prime essentials, considerable thought should be given to the location and maintenance of the road or driveway through the yard. The development of mudholes in which trucks might get stuck or of chuck holes endangering springs or parts, can not be tolerated, for a stuck or disabled truck generally means a delay to the mixer representing a loss of from 75 cents to a dollar per minute, despite the fact that the delay to the truck itself means the loss of only a few cents per minute. Thus, a long or slow passage through the material yard, so long as there is nothing to prevent orderly and regular progress, is not so serious. Even the worst yard condition of this kind would probably not mean more than one additional large truck or about $25 per day. On the other hand, three 10-minute mixer delays during the course of the day will probably exceed this loss.

As examples of the actual effect yard layout and management have in determining the length of time required for each vehicle to take on its load and pass through the yard, 24 rather typical jobs were selected, one half having a fairly good yard layout and able management and the other half with poor yard layouts and only fair to poor management. In this selection jobs using 1, 2, 3, and 4 batch trucks were all represented by 6 jobs for each size, one-half of which were good, well-managed layouts and the others inferior, poorly-managed layouts. These are given in Table 4, together with a comparison, for the same items, of the average values from over a hundred paving jobs having all kinds of layouts and grades of management.

It will be noted that the time differential in favor of the good as against the poor layout averages about 4 minutes, while the good layouts also show a differential of from about 1 to nearly 3 minutes below that of the average yard constant for all jobs. These are items too large to be ignored, as they may readily mean an unnecessary but permanent addition to the hauling equipment of at least the equivalent of one 3-batch truck.

TABLE 4.—*Effect of yard layout and management on magnitude of time constant*

GOOD YARD LAYOUT AND ABLE MANAGEMENT

Number of studies averaged	3	3	3	3
Size of trucks	1-batch.	2-batch.	3-batch.	4-batch.
Load aggregate ... seconds	10	38	70	98
Load cement bags ... do	12	29	54	84
Drive and maneuver ... do	48	65	87	62
Total net yard constant ... do	70	132	211	244

AVERAGE YARD LAYOUT AND MANAGEMENT [1]

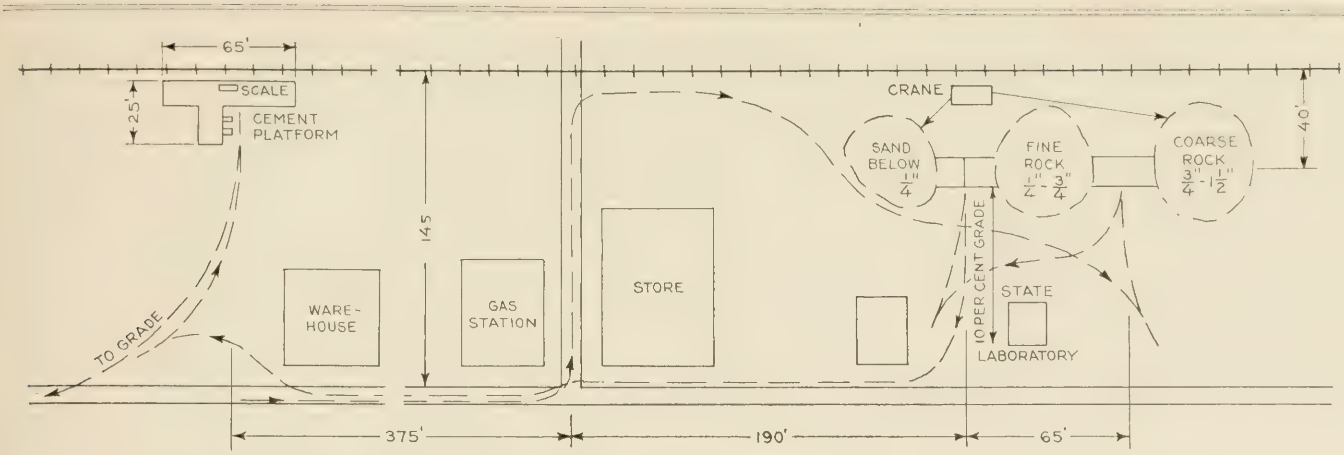
Size of trucks	1-batch.	2-batch.	3-batch.	4-batch.
Load aggregate ... seconds	15	59	114	190
Load cement bags ... do	28	80	106	110
Drive and maneuver ... do	81	99	102	100
Total net yard constant ... do	124	238	322	400

POOR YARD LAYOUT AND SLACK MANAGEMENT

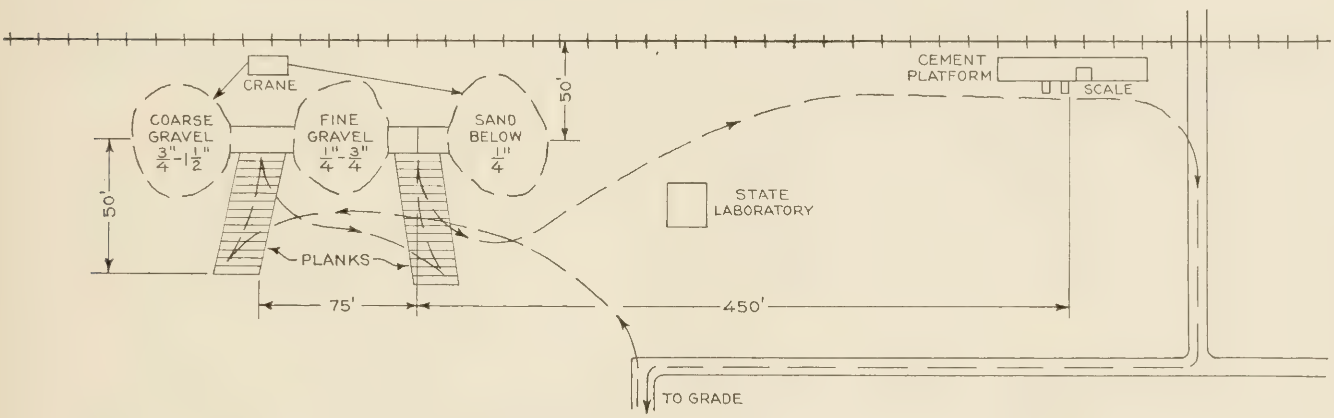
Number of studies averaged	3	3	3	3
Size of trucks	1-batch.	2-batch.	3-batch.	4-batch.
Load aggregate ... seconds	33	91	163	196
Load cement bags ... do	51	89	118	148
Drive and maneuver ... do	210	218	193	132
Total net yard constant ... do	294	398	474	476

[1] Average values for more than 100 jobs.

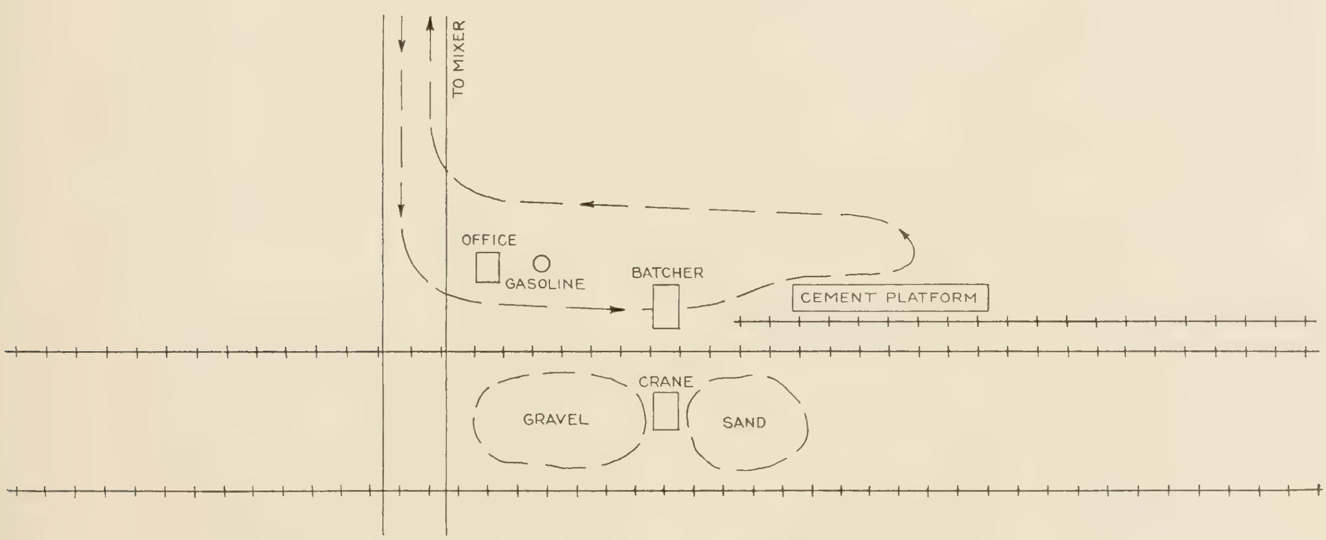
Every maneuver or operation within the yard requires time. To complete the usual 90° turn and back the truck under the bins ordinarily consumes from 20 to 30 seconds. With good batching facilities the actual standing time for a truck in taking on one batch of sand and coarse aggregate may regularly be as low as 10



A. TIME-CONSUMING YARD LAYOUT; TWO SIZES OF COARSE AGGREGATE; BULK CEMENT HANDLED WITH BUGGIES.



B. IMPROVED YARD LAYOUT; TWO SIZES OF COARSE AGGREGATE; BULK CEMENT HANDLED WITH BUGGIES



C. CONVENIENT YARD LAYOUT FOR ONE SIZE OF COARSE AGGREGATE AND BAG CEMENT

FIGURE 5.—EXAMPLES OF YARD LAYOUTS

seconds and need rarely exceed 20 seconds. The time required for multiple-batch trucks is much longer, so that from 20 to 40 seconds will usually have to be added for each additional batch. The use of two bins instead of one for loading the sand and aggregates is therefore found to increase the yard time constant of the trucks about 40 to 50 seconds for the 1-batch trucks, 75 to 90 seconds for 2-batch trucks, and from about 100 to 125 seconds for the 3-batch trucks under fair to good management and operating conditions when it is necessary to back under the bin. If the drive is straight through these figures can generally be reduced by from 20 to 40 seconds. This extra time for taking on the subsequent batches is due to the fact that the first batch can ordinarily be weighed out in the hopper and made ready to dump while the truck is coming in. But after this first batch is dumped the truck must then wait while the following batch is weighed out, which ordinarily requires from 20 to 30 seconds provided the sand flows readily.

Driving speed within the yard is, of course, low, seldom more than an average of 250 to 400 feet per minute. The average yard seems to have a yard loop or circuit which requires about 1½ minutes for the actual driving. The variation of individual yards from this average, however, is very large. The length of the yard circuit varies greatly while the driving conditions vary even more. Yards have thus been found which had a driving time as low as 35 seconds and others as high as 5 minutes. The importance of reducing the length of the driving circuit and improving the condition of the road should be apparent.

In a large contract there is often a possible choice of two or more locations for the loading plant. The question, then, arises as to whether to build entirely from one plant set-up or move to another as the work progresses. The cost of hauling of course varies as the length of haul plus the loading and unloading costs. But, to the concrete-paving contractor, the factor of regularity in the operation of the hauling units is of utmost importance. Thus, short hauls employing less vehicles are usually easier to organize into a smooth-functioning unit. While some surplus must always be maintained as insurance, the chance that this surplus will prove inadequate is always greater on the long hauls.

To ascertain the proper plant location and whether more than one should be used requires a knowledge of both hauling costs and the cost of dismantling, moving, and again assembling the plant at the new location. The cost of the hauling can be forecast with considerable accuracy provided the rental rates or rental value, the operating characteristics of the trucks which are to do the hauling, and the conditions under which the hauling is to be done are known. Of these, the operating characteristics are the most important as well as generally the most difficult to forecast, since they depend largely on both the yard layout and road or hauling conditions as well as the efficiency of the management. However, for any given job these factors can all be determined within reasonable limits by means of actual observations.

Having these data the following rather simple formula is suggested for forecasting the probable cost of hauling the batches for all or any desired part of the contract. If the cross section of the slab is not constant each portion so varied may be taken as a separate unit and the total cost will then be the sum of the several sections. The formula is as follows:

$$K=\frac{C}{60N}\left[T+\frac{60}{S}\ (L_1+L_2)\right]W \text{--------} \quad (1)$$

Where K = the cost of the hauling for section (L_1-L_2).

C = the hourly cost or rental value for the size and type of truck to be used.

N = the number of batches carried per load, or if tons per load W is also given in tons.

T = the total truck constant or average time the truck spends each trip at the mixer and in the yard, including all necessary and regular delays, in minutes.

S = the average actual round-trip speed in miles per hour while the truck is on the road.

L_1 = the dead-haul or hauling distance in miles from batcher plant to beginning of concrete slab being laid.

L_2 = the total length of haul in miles from batcher plant to end of the section under consideration.

W = the total number of batches (or tons if N is given in tons per load) to be hauled for the section under consideration. If the cross section is not uniform a separate computation should be made for each distance involving a changed section length.

With a slight modification this formula can also be used for forecasting the cost of hauling per batch-mile or per ton-mile, or the total cost of hauling a batch or a ton any given distance, L. The cost of hauling per batch-mile or ton-mile is given by the expression,

$$B=\frac{C}{60N}\left(\frac{T}{L}+\frac{120}{S}\right) \text{---------------} (2)$$

and the total cost of hauling a batch the distance L is given by the expression,

$$D=\frac{C}{60N}\left(T+\frac{120}{S}\ L\right) \text{-------------} (3)$$

in which B = the cost of hauling per batch-mile when N is batches per load or per ton-mile when N is tons per load.

D = the total cost of hauling a batch or ton the distance L.

L = the actual length of haul, including dead haul.

All other factors are the same as in formula 1.

In determining whether or not the hauling should actually be done from two or more yards instead of from one, the following points should also be given careful consideration in addition to the solution of the cost of the haul itself:

1. The cost of moving and setting up on the new location.
2. The cost of materials laid down at the new yard.
3. Track and switching facilities at the new yard.
4. Adaptability of the available space for a yard layout.
5. Hauling and traffic conditions from the proposed location.
6. Probable time constant for new yard and yard operation cost.

Each of these items may have a very definite bearing on whether the move should or should not be made; yet, each case is likely to have so many special conditions that general rules are apt to prove of little value. Thus the actual total cost of making the move and getting ready to operate from a second location only 5 or 10 miles distant may readily vary from $500 to $5,000, while the actual time the paving work will be down may vary from one day to more than a week. No simple rule, such as the stipulation that if the haul can be reduced by some given amount a second yard should be used, will suffice to meet the varying conditions. Every case must be carefully investigated. Such items as freight rates, land rentals, switching and track facilities, as well as reliablity of delivery of materials are seldom the same for any two possible locations and may be sufficient to overbalance any possible saving from the shorter haul. The second location, for example, may be on a different railroad, so that the freight rates may be either higher or lower by a considerable amount;

or, again, the rates may be the same, but the new location may involve the transfer of the cars in transit from one system to another at some point where exchanges are more or less infrequent and therefore likely to make delivery slow and irregular. Such a location would be undesirable unless space were available for more than normal stock piling.

Sometimes siding facilities are inadequate, especially when two or more sizes of coarse aggregate are required. The installation of an additional spur is usually rather expensive. The work involved in providing a satisfactory driveway, as well as suitable locations for the bins, cement platform and storage shed, and stock-piles is seldom the same in any two cases. Careful advance investigation will nearly always produce the data from which the cost and time required for developing the new location can be estimated with reasonable accuracy.

Another item which must not be overlooked is that of traffic conditions in connection with the new yard. Congested highway traffic is always bad in that it limits speed and tends toward irregularity. Railroad grade crossings over main lines carrying heavy traffic are always dangerous, while those over freight-passing sidings are apt to occasion frequent and sometimes long delays. Conditions have been found where as many as two extra 3-batch trucks and a crossing watchman were required to prevent serious delays to the mixer. This is equivalent to a tax of 12 to 15 cents on every batch handled from such a yard when production is high, and correspondingly more when production is low.

In general, we find that for any influence which increases the truck time constant the capacity of the hauling equipment must be increased one batch for each mixing cycle added to the length of the time constant. Thus, if the regular mixing cycle is 1¼ minutes, then an increase of 2½ minutes in the time constant on a job using 2-batch trucks will require the full time addition to the hauling equipment of one additional 2-batch truck of the same type and speed as those used on the job.

The actual process of determining whether a second yard should or should not be used for any particular job might be illustrated as follows: Contractor A has a job 7 miles in length which will require 2,000 batches per mile. One end of the job is a half-mile from the siding where the materials plant can be located with ample room for storage. A second siding where an equally advantageous yard can be located and where hauling conditions are similar to the first, is 2½ miles beyond the far end of the road. The question before the contractor is whether or not the saving in hauling costs from two set-ups will exceed the cost of making the move. The contractor, after examining the proposed location and securing data as to freight rates, ground rentals, etc., makes his estimates about as follows.

He is using 3-batch trucks which are costing him at the rate of $3 per hour. For this location these trucks will have a time constant of about 10.5 minutes and maintain an average round-trip speed of 20 miles per hour, which is the same as at the present yard. Freight rates and switching charges happen to be the same for both sidings. The cost of moving the yard and making the new set-up will require two working days. His straight-time pay roll amounts to $65 a day, and about $60 a day for additional labor will be required during the two days of moving and setting up at the second yard, making the direct labor cost $250. After allowing for salvage value of lumber at the old yard, the cost of materials and erection of the cement loading platform, shop, office, and storage shed will amount to $250. Loss of material in cleaning up base of stock piles, he estimates at $100. Incidental materials, gas, oil, etc., are placed at $100. Ground rental and miscellaneous items add another $100. The cost of moving the yard will therefore be $800, aside from the loss of two working days and a temporary disorganization of his working force.

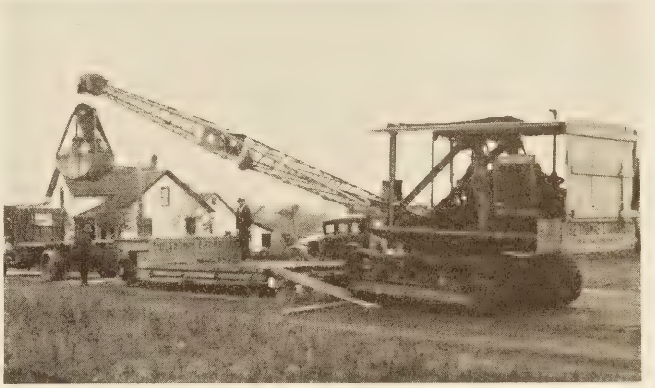


FIGURE 6.—THE USE OF HEAVY TRAILERS SOMETIMES FACILITATES THE MOVING OF HEAVY EQUIPMENT

Against this cost he must balance the possible saving to be secured from a reduced hauling distance for 2½ miles of the contract, so that his maximum haul, instead of 7½ miles from the one set-up, will be only 5 miles from each of the two set-ups. Substituting the above data in formula No. 1, we find that the probable cost for hauling the entire job from the first yard would be $8,050, while the cost of hauling for 4½ miles from the first and 2½ miles of the job from the second yard would be $6,800, a margin of $1,250 in favor of using the two yards. Since he finds that the cost of making this move would probable not exceed $800, the move in this case is justified.

The many and variable factors which enter into batcher plant operation make the drawing of general conclusions very difficult and generally impossible. An analysis of the data secured by means of detailed stop-watch studies on more than a hundred going jobs all serve to direct attention to this one feature: That the attainment of low unit costs in handling, batching, and hauling the materials which enter into our concrete roads is not a matter of chance or of luck, but the result of careful advance planning and constant supervision by an able and alert management.

INDEX TO VOLUME 12 OF PUBLIC ROADS AVAILABLE

An index to volume 12 of PUBLIC ROADS, which includes the issues from March, 1931, to February, 1932, is now available for distribution, and copies may be obtained from the Bureau of Public Roads, United States Department of Agriculture, Washington, D. C. Indexes to volumes 6, 7, 8, 9, 10, and 11 have previously been published, and a supply of these indexes is still on hand.

CONNECTICUT AVENUE EXPERIMENTAL ROAD NOW 20 YEARS OLD

THE CONNECTICUT Avenue experimental road, extending from Chevy Chase Circle to Chevy Chase Lake in Montgomery County, Md., was built during the years 1911, 1912, and 1913 by the Bureau of Public Roads. The road was constructed as two separate projects, the dividing line being at Bradley Lane. South of that point sections were constructed of water-bound macadam with subsequent bituminous surface treatment and also sections of bituminous macadam. North of Bradley Lane the sections consisted of Portland cement concrete and of bituminous concrete and brick on Portland cement concrete foundation.

All of these experimental sections are now either 19, 20, or 21 years old and all are in service under a heavy traffic. Beginning with the present issue a series of photographs is to be published on the cover of PUBLIC ROADS showing sections of the various types of construction immediately after completion and their appearance to-day after the lapse of 20 years.

The section chosen for this issue is a portion of experiment 3, which is composed of penetration bituminous macadam in which a fluxed native asphalt was used. This project was constructed in 1911. The photographs on the back cover include a construction picture and a view of the finished pavement several months after completion. The front cover shows its present condition.

The initial cost of this section of bituminous macadam was 64.69 cents per square yard. In 1918 a surface treatment costing 20.84 cents per square yard was applied. Maintenance costs prior to 1918 totaled 1.44 cents per square yard. Since 1918 a total of 9.62 cents per square yard has been spent for maintenance. The traffic has been increasing steadily since the road was built, and in 1931 reached an average density of over 4,000 vehicles per day.

It is recognized that there are many other roads in the country which have reached an age of 20 years or more. The bureau would be glad to receive from the readers of PUBLIC ROADS descriptions, with photographs, of road surfaces which have stood the test of time.

(Continued from p. 96)

Figure 1. This shows how dissimilar asphalts and distillates may be combined to produce finished cut-back products of identical character and demonstrates why the consumer should not attempt to control the characteristics of the original components of a cut-back or blended product.

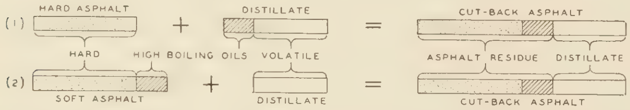


FIGURE 1.—DIAGRAM SHOWING HOW CUT-BACKS OF IDENTICAL CHARACTER MAY BE FORMED FROM DISSIMILAR ASPHALTS AND DISTILLATES

CONCLUSION

The liquid asphaltic road materials which are involved in this cooperative undertaking are manufactured and sold by a great number of producing companies which, from the commercial standpoint, may not always have a common interest. They are furnished in vast quantities, in a number of grades and for varied purposes, to practically every State and are required to meet specifications which, to a great extent, are peculiar to the individual State and have been developed by the State as a result of its own experience. When one considers the conflicting interests and the varied opinions which exist; the general acceptance of the many tests which have been in long-continued and unquestioned use; and the somewhat violent challenge to current practice which is contained in the proposed simplified scheme of analysis, the degree of approval which has been given it after only a year of study, and the degree to which tests outside its scope have been eliminated, may be considered to be truly remarkable. This accomplishment would not have been possible without the wholehearted cooperation which has been given by the manufacturers and the State highway departments. That all have contributed so generously to the work is evidence of the keen appreciation that drastic changes in present practice are to be desired.

Much remains to be accomplished before the desired degree of simplification and standardization of a common scheme of analysis can be effected, and beyond this there is the further need of agreement regarding specification test limits which will establish a series of standard grades of material for the various types of construction. The progress which has been made gives promise of ultimate success in securing the needed improvements in existing practice.

CORRECTIONS

Vol. 13, No. 2, April, 1932.—In the article entitled "The Resistance of Concrete to Frost Action," page 35, it was erroneously stated that aggregate No. 5 was a gravel from Millville, N. J. This gravel was obtained from Farmingdale, Monmouth County, N. J.

Vol. 13, No. 3, May, 1932.—In the article entitled "Concrete Pavement Design Features, 1931," the table on page 50 gives the width of concrete pavement on projects submitted by the State of Washington as 18 feet. The standard width in Washington is 20 feet. Out of 67 miles of concrete paving on Federal-aid projects submitted by this State during 1931, there were 63½ miles of 20-foot pavement and 3½ miles of 18-foot pavement.

UNITED STATES DEPARTMENT OF AGRICULTURE

BUREAU OF PUBLIC ROADS

CURRENT STATUS OF FEDERAL-AID ROAD CONSTRUCTION

AS OF

JULY 31, 1932

STATE	COMPLETED MILEAGE	UNDER CONSTRUCTION						APPROVED FOR CONSTRUCTION					BALANCE OF FEDERAL-AID FUNDS AVAILABLE FOR NEW PROJECTS	STATE
		Estimated total cost	Federal aid allotted	Percentage completed	MILEAGE Initial	MILEAGE Stage[1]	MILEAGE Total	Estimated total cost	Federal aid allotted	MILEAGE Initial	MILEAGE Stage[1]	MILEAGE Total		
		$	$					$	$				$	
Alabama	2,405.2	1,638,442.00	797,324.95	96	62.8		62.8						5,469,694.24	Alabama
Arizona	1,229.4	2,431,284.00	1,750,127.23	70	94.4	61.7	156.1	4,594.57	3,459.24		0.3	0.3	810,004.99	Arizona
Arkansas	1,960.2	2,451,768.24	1,127,328.92	86	64.8	45.1	109.9	362,032.53	181,016.26	17.3		17.3	2,183,603.25	Arkansas
California	2,359.9	9,507,941.91	4,533,068.35	55	209.3	49.5	258.8	610,039.47	188,171.69	27.5	4.4	31.9	130,615.78	California
Colorado	1,632.1	3,754,986.86	1,987,694.54	78	155.0	45.7	200.7						2,058,274.18	Colorado
Connecticut	287.0	4,071,872.74	1,479,495.06	76	24.9		24.9	710,239.12	337,234.32	10.3		10.3	329,792.14	Connecticut
Delaware	363.2	711,647.00	355,823.50	70	23.7		23.7	86,524.00	43,262.00	4.7		4.7	167,140.82	Delaware
Florida	641.4	3,489,185.36	1,613,648.03	86	99.1		99.1	658,535.24	322,435.77	17.3		17.3	2,544,886.16	Florida
Georgia	3,081.0	6,400,105.13	2,994,218.88	69	149.3	167.0	316.3	127,270.50	63,635.24	4.6	1.2	5.8	1,351,969.22	Georgia
Idaho	1,417.6	2,524,336.26	1,495,426.51	76	112.7	149.6	262.3	1,283,119.89	770,043.65	45.1	184.0	229.1	156,658.16	Idaho
Illinois	2,702.4	25,150,518.35	11,663,716.64	79	757.6	36.8	794.4	2,354,574.70	1,003,165.26	79.9	5.3	85.2	1,332,521.57	Illinois
Indiana	1,851.0	10,346,805.27	5,130,201.91	45	378.7	20.5	399.2	761,496.48	380,730.95	36.0		36.0	341,205.50	Indiana
Iowa	3,324.8	5,412,086.54	2,525,295.18	37	255.1	65.7	320.8	714,471.56	231,710.02	30.2	18.9	49.1	42,800.00	Iowa
Kansas	3,620.5	5,277,872.95	2,593,581.92	67	296.3	99.9	396.2	1,834,697.90	887,701.29	61.6	267.8	329.4	560,318.87	Kansas
Kentucky	1,892.3	2,645,916.04	1,187,938.37	74	161.6	16.0	177.6	1,627,756.73	633,752.98	38.8	91.2	130.0	983,390.78	Kentucky
Louisiana	1,567.5	7,456,322.25	3,503,393.25	49	87.0	9.9	96.9						868,290.73	Louisiana
Maine	721.3	3,981,360.08	1,735,005.26	65	116.3		116.3	104,593.33	52,296.66	.3		.3	191,004.42	Maine
Maryland	778.9	1,170,603.98	484,776.57	58	38.9	.6	39.5	1,149,155.55	462,712.12	45.0	5.6	50.6	8,817.81	Maryland
Massachusetts	817.3	7,129,265.67	2,897,641.92	80	71.3	.2	71.5	285,726.10	142,863.04	2.2	6.5	8.7	459,748.73	Massachusetts
Michigan	2,084.4	9,978,642.29	4,578,493.99	76	391.6	31.9	423.5	1,162,226.40	545,502.50	21.2	45.5	66.7	1,772,525.53	Michigan
Minnesota	3,948.2	11,543,711.88	3,804,301.38	58	205.0	304.7	509.7	583,201.84	175,000.00	15.6	12.3	27.9		Minnesota
Mississippi	1,809.0	3,875,720.84	1,898,233.36	87	171.2	68.8	240.0	75,492.84	37,746.42	16.1		16.1	5,191,098.68	Mississippi
Missouri	2,928.7	7,007,407.19	3,040,641.57	51	185.0	97.1	282.1	361,486.67	173,742.54	18.7	2.9	21.6	562,565.24	Missouri
Montana	2,759.5	3,972,279.91	2,230,226.09	79	362.5	31.5	394.0	275,936.51	154,007.78	5.7	98.4	104.1	3,299,347.07	Montana
Nebraska	4,284.9	2,794,323.43	1,386,098.91	71	122.1	26.1	148.2	1,813,356.01	841,768.57	28.2	111.6	139.8	1,861,142.54	Nebraska
Nevada	1,256.6	2,218,423.33	1,887,476.60	63	40.6	187.6	228.2	194,252.66	172,521.31	7.4	39.9	47.3	10,830.62	Nevada
New Hampshire	421.0	548,058.81	244,966.84	54	17.1	2.5	19.6	41,149.53	20,574.76	2.4		2.4	428,596.59	New Hampshire
New Jersey	623.6	4,314,673.59	1,554,698.78	53	27.9	.5	28.4	1,131,894.01	565,947.00	.3		.3	603,796.98	New Jersey
New Mexico	2,239.0	1,692,957.16	1,189,247.98	79	78.3	31.4	109.7	690,644.66	409,067.23	22.2	29.1	51.3	906,657.37	New Mexico
New York	3,280.6	16,525,600.00	7,429,600.00	50	402.8		402.8	4,894,980.00	1,824,190.00	106.6		106.6	1,659,610.27	New York
North Carolina	2,226.4	1,199,041.83	590,635.84	77	68.0	5.0	73.0	310,669.92	154,517.62	6.9	20.9	27.8	3,701,148.36	North Carolina
North Dakota	5,016.0	3,759,681.72	1,885,597.27	53	483.5	338.0	821.5	1,479,246.33	747,558.95	104.4	427.8	532.2	762,530.67	North Dakota
Ohio	2,879.7	6,861,611.07	2,236,780.15	68	132.4	25.6	158.0	6,161,923.90	2,336,854.89	156.0	58.4	214.4	929,626.00	Ohio
Oklahoma	2,303.6	3,668,796.96	1,727,629.03	78	184.3	36.7	221.0	2,100,324.42	1,081,218.89	112.5	17.6	130.1	870,605.64	Oklahoma
Oregon	1,558.4	3,597,543.02	1,989,194.21	75	99.0	43.1	142.1	1,030,058.22	586,479.02	44.3	65.6	109.9	899,554.97	Oregon
Pennsylvania	3,025.5	6,916,867.26	3,295,528.18	29	277.1		277.1	4,390,531.74	1,924,475.86	116.5		116.5	511,078.08	Pennsylvania
Rhode Island	257.8	802,583.73	397,179.71	73	16.6		16.6						326,325.34	Rhode Island
South Carolina	2,049.9	2,366,835.31	1,065,169.32	98	60.4	41.4	101.8						744,636.09	South Carolina
South Dakota	4,004.6	3,846,371.88	2,262,747.75	65	304.9	218.6	523.5	198,838.04	110,414.74	13.2	27.1	40.3	799,610.50	South Dakota
Tennessee	1,670.5	1,804,913.59	885,932.91	54	61.9	19.4	81.3	559,531.22	279,080.49	10.2	8.7	18.9	3,012,060.90	Tennessee
Texas	7,757.2	14,518,790.54	6,661,286.22	71	657.2	261.8	919.0	4,606,578.85	2,104,664.82	240.0	220.0	460.0	2,513,758.06	Texas
Utah	1,164.4	1,341,973.90	974,822.93	67	90.0	66.8	156.8	656,678.26	496,284.08	49.2	69.2	118.4	482,931.79	Utah
Vermont	339.1	1,416,419.92	634,311.33	35	45.7		45.7							Vermont
Virginia	1,922.4	1,914,628.55	957,314.21	75	112.3	6.2	118.5	814,945.19	371,890.68	30.3	21.6	51.9	1,766,774.90	Virginia
Washington	1,216.8	2,846,109.67	1,355,994.35	70	92.0	14.5	106.5	837,651.47	305,300.00	17.9	5.3	23.2	824,469.51	Washington
West Virginia	893.3	1,893,304.80	823,391.31	77	48.7	10.5	59.2	952,257.00	466,971.47	33.4		33.4	609,263.59	West Virginia
Wisconsin	2,598.5	7,774,738.25	3,190,598.32	55	206.7	70.7	277.4	1,003,163.91	393,400.00	29.5	20.1	49.6	335,738.52	Wisconsin
Wyoming	1,942.3	3,425,976.48	2,135,753.94	75	176.4	225.1	401.5						123,028.57	Wyoming
Hawaii	76.3	876,665.56	460,511.05	61	23.5		23.5	674,545.52	533,085.24	17.2	3.6	20.8	1,335,908.87	Hawaii
TOTALS	101,191.2	240,856,973.10	112,630,070.52	65	8,303.5	2,933.7	11,237.2	49,676,392.79	22,516,455.35	1,646.7	1,890.8	3,537.5	56,835,958.60	TOTALS
Construction completed		155,701,000	73,383,000											
Balance uncompleted		85,156,000	39,247,000											

[1] The term stage construction refers to additional work done on projects previously improved with Federal aid. In general, such additional work consists of the construction of a surface of higher type than was provided in the initial improvement.

CONNECTICUT AVENUE EXPERIMENTAL ROAD, CHEVY CHASE, MD., NOVEMBER, 1911, SHOWING APPLICATION OF SEAL COAT IN THE FOREGROUND AND FINISHED BITUMINOUS MACADAM ROAD IN THE DISTANCE

SURFACE CONDITION OF BITUMINOUS MACADAM SECTION IN MAY, 1912. THE PHOTOGRAPH ON THE FRONT COVER WAS TAKEN AT THE SAME LOCATION

U. S. GOVERNMENT PRINTING OFFICE: 1932